ENTRAINMENT IN AIR JETS

BY

HOWARD LEE GRIMMETT

B.S., University of Michigan, 1944
M.S., University of Illinois, 1948

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CHEMICAL ENGINEERING
IN THE GRADUATE COLLEGE OF THE
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ENTRAINMENT IN AIR JETS

Introduction

The properties of gas jets have important bearing on the design of equipment such as injectors, gas burners, spray dryers, and wind tunnels. The velocity field for an air jet, discharging to the atmosphere and entraining air of the same density, has been studied both theoretically and experimentally by others. Experimental studies by Taylor et al[1] led to a good empirical correlation of the jet field.

The purpose of this paper is to apply the correlation for free jets to more complex systems. Three different systems were studied; the first system consisted of two geometrically similar parallel nozzles, the second of a nozzle and a large flat plate with the jet axis parallel to the plate, and the third consisted of a jet discharging into a round straight duct.

Two Parallel Nozzles

The two nozzles were mounted in a bracket so that their axes were parallel and 3 inches apart. The discharge sections were in the same plane. Velocity traverses were taken with a calibrated impact tube at several different distances from the nozzles in a plane through the axes of the nozzles. Traverses were also taken in a direction normal to this plane. The measured velocity distribution was compared with that predicted by assuming that the momentum flow at any point was equal to the sum of the momentum flows for the two nozzles separately at that point. Or if u_1 is the velocity at a given point with nozzle 1 operating alone, and u_2 is the velocity at the same point with nozzle 2 operating alone, then

$$\rho u^2 = \rho u_1^2 + \rho u_2^2 \qquad (1)$$

where u is the velocity at the given point with both nozzles operating. The predicted and experimental profiles showed good agreement, especially at large distances from the nozzle.

The only deviations were in the zone between the two nozzles. The maximum error ranged from 7% at 15 nozzle diameters and decreased to about 3% at 30 nozzle diameters.

Nozzle and Flat Plate

The flat plate was located 1.5 inches from the nozzle axis. Velocity profiles were taken at several distances from the nozzle discharge in a plane normal to the plate and through the nozzle axis. The experimental profiles were compared with those predicted by assuming that the momentum "particles" hitting the plate were reflected perfectly. On the basis of this assumption, the predicted profile should be the same as the profile from two parallel nozzles 3 inches apart since the reflected portion of the field can be thought of as coming from a mirror image of the nozzle in operation. The predicted and experimental profiles showed the same order of agreement as in the case of two parallel nozzles, except that at axial distances larger than 20 nozzle diameters this method of prediction was no longer valid since the boundary layer along the plate became important.

Nozzle Issuing Into A Round Straight Duct

Two different seamless steel tubes were used. One was 2.8 inches in inside diameter by 30.2 inches long, the other 3.75 inches in inside diameter by 20.12 inches long. In all cases the nozzle exit was located 15 nozzle diameters from the duct entrance. At this distance part of the jet expanded around the duct. Velocity profiles inside the duct were measured for nozzle exit velocities of 346 and 500 ft./sec. for the larger duct and for 496 ft. sec. for the smaller duct. Wall tap static pressures along the duct were also measured. Comparison between the experimental duct entrance profile and the profile for a single jet at 15 nozzle diameters showed very close agreement, all deviations being within the estimated experimental error of 2%.

Values of the average or bulk velocity computed from the velocity profiles were constant with distance from the duct

entrance indicating constant gas density inside the duct. The values of the correction factor α defined by:

$$\alpha\rho v^2 A/g_C = \text{momentum flux}$$
$$\rho = \text{density } \#/\text{ft.}^3$$
$$v = \text{bulk velocity ft./sec.}$$
$$A = \text{duct area ft.}^2$$

were calculated from the experimental velocity profiles. α was correlated graphically by plotting $\alpha - 1/\alpha_{A-1}$ against L/D where α_A is the value of α at the duct entrance, L is the distance from the duct entrance, and D is the duct diameter. The ratio $\alpha - 1/\alpha_{A-1}$ was found to be a function of L/D only and independent of nozzle exit velocity and of duct dimensions. Using this correlation and the momentum balance equation

$$(p_B - p) = \rho v^2/g_C\ (\alpha - \alpha_B) \qquad (2)$$
$$p = \text{static pressure at any plane}$$
$$p_B = \text{static pressure at duct exit}$$

it was possible to calculate static pressures inside the duct which agreed closely with the experimental values.

Conclusions

The following conclusions were reached:

1. The velocity field from two parallel nozzles can be predicted to a good degree of approximation by assuming the additivity of momentum from the two sources at a given point.

2. The assumption of momentum reflection gives a good approximation to the velocity field from a nozzle discharging adjacent to a solid surface. At large axial distances this concept is complicated by the importance of the boundary layer.

3. For a jet issuing into a duct, where the jet stream completely fills the duct at the entrance, the mass flow, and the value of α at the duct entrance may be calculated from the velocity profile of a free jet at the axial distance corresponding to the duct entrance. By using these quantities along with the

α correlation presented, the static pressure distribution inside the duct may be calculated.

BIBLIOGRAPHY

1. Taylor, J. F., Grimmett, H. L., and Comings, E. W.: Paper to Be Published.

VITA

The author was born in Benton, Illinois, on December 30, 1922. He attended the public schools of Benton, Illinois, graduating from Benton Township High School in 1940. He then attended Northwestern University and the University of Michigan, receiving the degree of Bachelor of Science in Chemical Engineering from the latter in 1944. From 1944 to 1946 the author was in the United States Army, spending the major portion of this time assigned to the Manhatten Project in Oak Ridge, Tennessee. In 1946 he entered the University of Illinois as a graduate student, receiving the degree of Master of Science in Chemical Engineering in 1948. While at the University of Illinois, he held an appointment as a special research assistant in the Engineering Experimental Station on a contract with the Office of Naval Research, N6-ori-71, Task Order XI, entitled "The Mixing of Fluid Streams."

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